Response to FCC 98-208 Notice of Inquiry in the Matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems

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INTRODUCTION

TEM Innovations is a technology generation firm headed by the inventor of Micropower Impulse Radar (MIR). MIR is a low-cost UWB impulse technology that has attracted over 5000 inquiries and has been licensed to dozens of companies by Lawrence Livermore National Laboratory. Wideband (WB) pulsed-RF sensors currently in development at TEM Innovations are also generating the same high level of interest (see pages 3-5 for examples of WB technology).

The FCC can enable this new technology on three levels, each providing a greater amount of opportunity for commercial development. The Commission is urged to consider the following *Options*:

1. Do not apply pulse desensitization correction (PD) to wideband emitters in the 15.209 bands (see page 13). PD is unnecessary, inappropriate, impractical, and it blocks the growth of WB and UWB sensor technology in the US. ***This Option will enable 90% of all low power WB and UWB sensor applications.*** *Operation in the restricted bands is* ***not*** *required.*

2. Combine Option 1 with the removal of the distinction between intentional and unintentional radiation, only for operation in the restricted bands adjacent to the ISM bands at 2.4, 5.8, 10.5 and 24GHz. This would allow higher power operation in the ISM bands with low sidelobe radiation into the adjacent restricted bands. ***This Option will enable nearly 100% of all WB and UWB sensor applications, including moderate power emitters.***

3. Combine Options 1 and 2 with the allowance of intentional radiation into all the restricted bands. Since this will create unacceptable interference to GPS receivers and FAA radars, licensed operation will be mandatory. ***This Option will enable nearly 100% of all WB and UWB sensor applications <u>and</u> subsurface imaging.***

WB and UWB technology is of great interest and importance because it brings the ***speed*** of light to society as its new genie. In comparison, the laser relies on the ***purity*** of light, and took decades to find commercial application. The speed of light is about to revolutionize society with new sensors that will form the third leg of a cybernetic “eyes-nerves-brain” or “sensors-communications-computer” triad of the future.

Much of this new sensor technology is attractive because it time-expands realtime microwave signals into “equivalent time” signals that are slowed by a factor of 1-million. It is as though the speed of light were slowed 1-million times through a stroboscopic effect. Thus, microwave signals can be identically represented by audio signals for vastly simplified communication to a computer for intelligence processing. See Figure 2 on page 3 for an example of a microwave signal that has been time-expanded 1-million times with low cost circuitry.

In teaming with communications and computers, microwave sensors will be the hottest technology of the next decade. No other sensor technology can match their combination of features:

- Operation through building walls, instrument and automotive panels, ceramic bath fixtures, water spray, snow, ice, dirt and grease
- Precision location and ranging
- Speed and direction measurement
- Formation of a radar “bubble” or bounded sensing region
- Imaging of hidden or subsurface objects
- Operation for years on a small battery
- Collocation of large numbers of sensors
- Communication at high data rates between chips
- Competitive low cost.

QUESTIONS POSED BY THE FCC

9A. What types of UWB devices can we expect to be developed?

The following devices can be implemented with either WB or UWB technology:

- **Radar Rangefinders** for industrial, commercial and residential distance measurement, safety devices and automation. For an example, see Figure 1.

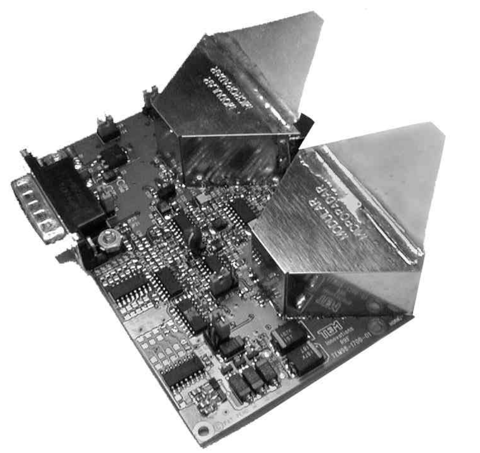

Figure 1. This low-cost, precision 5.8GHz wideband radar rangefinder was developed by TEM Innovations for 1mm accuracy over a 10-meter range. Applications include precision tank level measurement, robotics and general obstacle detection. Its emissions are shown in Figs. 2 and 3. This WB technology has already been licensed to overseas interests, but will not pass FCC limits when PD correction is applied in the 15.209 bands. A 24GHz version is near completion and will also be licensed overseas.

Figures 2 and 3 show a 5.8GHz wideband (WB) radar pulse and its spectrum, respectively, for the radar of Figure 1.

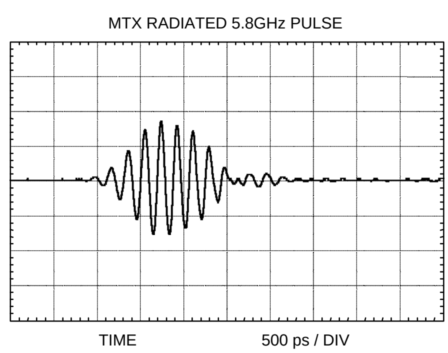

Figure 2. A 5.8GHz WB radar pulse. This signal has been slowed 1-million times by the radar in Fig. 1 for simplified processing. (Realtime scale shown)

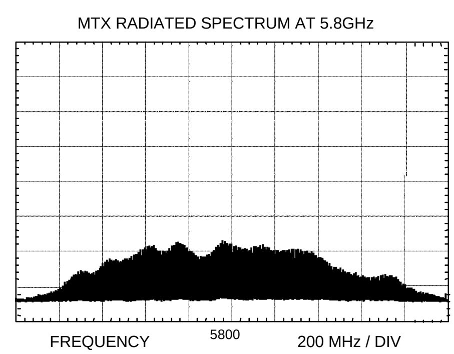

Figure 3. The 5.8GHz WB radar spectrum of Figure 2.

- **Motion / proximity sensors** for security, home and industrial automation, countless consumer devices. For an example, see Figure 4.

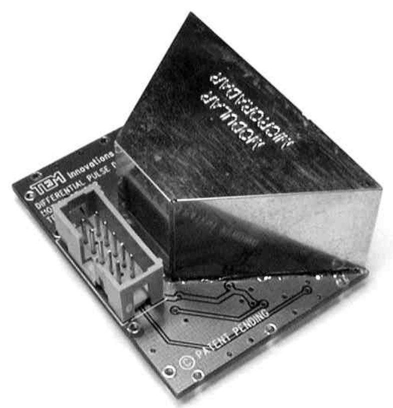

Figure 4. This 5.8GHz wideband Differential Pulse Doppler motion sensor was developed by TEM Innovations to provide nearly constant Doppler response versus range within a gated cell. A quadrature Doppler version is available for direction sensing or complex processing. Uses include home and industrial security and automation. This WB technology is in the licensing process to overseas interests, but will not pass FCC limits when PD correction is applied in the 15.209 bands.

- **Imaging radar** for subsurface object imaging and location, police work, and medical applications. TEM Innovations has developed a low-cost 32-element UWB impulse array for subsurface imaging and medical tomography. This UWB technology is in the licensing process to overseas interests, but will not pass FCC Regulations due to radiation into the restricted bands.

- **Radiolocation devices** for computer applications, location of people and objects, and localizing RFID tags. TEM Innovations has developed a wideband 5.8GHz radiolocation system with sub-mm resolution over a 3-meter area for computer digitizing inputs. This WB technology has already been licensed to overseas interests, but will not pass FCC limits when PD correction is applied in the 15.209 bands.

- **New sensors** too innumerable to list. A sampling might include a WB vibration sensor for guitar pickups and for high accuracy speech recognition, as seen in Fig. 5.

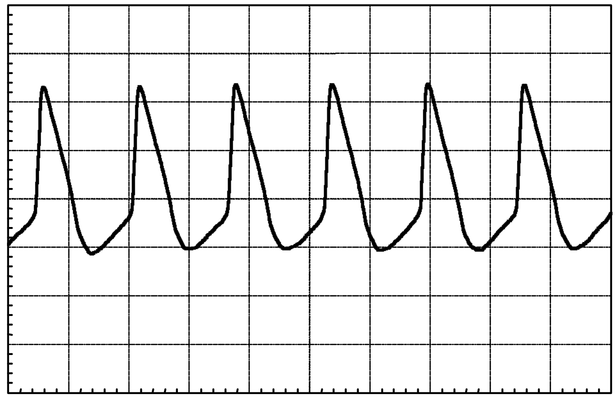

Figure 5. Human vocal cord vibration detected with a micropower 2.4GHz wideband pulsed-RF vibration sensor placed near the Adam's apple. The clock-like waveform remains clean during speech and can be correlated with microphone data for enhanced speech recognition**.** The waveform represents the raw carrier upon which speech is modulated, and is not obtainable by filtering microphone data. This WB technology is in the licensing process to overseas interests, but will not pass FCC limits when PD correction is applied in the 15.209 bands.

The FCC's inappropriate use of pulse desensitization (PD) correction is blocking the development and deployment of the next millenium's hottest sensor technology in the United States. Overseas interests are already beginning to enjoy the benefits of US innovation at the expense of US competitiveness.

9B. What are the frequency ranges and bandwidths expected to be used by UWB devices?

Frequency preference is primarily based on

- Target size
- Clutter size
- Antenna size
- Antenna beamwidth
- Materials penetration.

The following two examples illustrate why access to various spectral regions is desirable. Both relate to the detection of large targets:

1. **Intrusion alarm**. A major problem with motion sensors is false triggering on clutter, such as fluttering leaves. The best target/clutter contrast can be obtained at long wavelengths where reflection from leaves is very poor, falling off as the 4th power of size-to-wavelength ratio. Thus, a 915MHz system would provide

much higher contrast than a 10.5GHz system. Operation at longer wavelengths has the additional advantage that it can penetrate walls. However, without range-gating the sensor is prone to triggering on any large distant object. Range-gating requires WB or UWB operation.

2. **Tank radar**. The liquid in a tank is a large target, but wall reflections are a serious problem. Wall reflections can be eliminated with UWB radar by time-gating. However, a 5.8 or 24GHz WB radar is preferable because (a) a highly desirable small footprint antenna can be used, (b) interference from cell phones is eliminated, (c) a narrow-beam antenna can be used to reduce/eliminate wall reflections, (d) time-gating can be applied, and (e) cost is low.

WB and UWB spectrum requirements may be approximated by the following table:

Device	Frequency Range	Bandwidth
Rangefinder	5.8 – 64GHz	0.5 – 5GHz
Radio Location	0.9 – 64GHz	0.1 – 5GHz
Motion & Proximity sensors	0.9 – 64GHz	.01 – 5GHz
Subsurface imager	0.1 – 5GHz	.2-10GHz

9C. What are the expected total power levels and spectral power densities, peak and average, of UWB devices?

The following table applies to either WB or UWB devices:

Peak transmit levels	3 Volts or +20dBm
Average transmit power	< 1 milliwatt
Bandwidth	0.1-5GHz
Center Frequency	0.1-60GHz
PRF	0.1-10MHz
Duty cycle	<10% with 0.1% typical
Spectral density	<5000µV/m at 3m

9D. What are the expected or desired operating distances?

Short range, typically 1cm to 30-meters.

10A. Are there certain types of UWB devices or applications that should be regulated on a licensed basis under some other rule part? If so, which rule parts?

Part 15 is the most appropriate Part for unlicensed operation, provided that microwave sensing is given equal regulatory status to other telecommunications. The Commission should license, under another Part, GPR and other limited-usage professional UWB applications that radiate into the restricted bands.

10B. If provisions are made for UWB technology under Part 15, how should we define UWB technology?

The definition should reflect the low spectral density aspect of WB and UWB systems:

WB-LP (wideband low power) = greater than 10MHz bandwidth and 15.209 emission levels

11A. Should the rules generally continue to prohibit operation of UWB systems within the restricted bands and the TV broadcast bands?

Yes. UWB emissions will negatively impact GPS and FAA radar, and possibly other vital services. In contrast, wideband (WB) systems provide an alternative solution for virtually all commercial interests while leaving the restricted bands undisturbed.

The following tests and calculations reveal the deleterious impact UWB will have on restricted band users. UWB will impact FAA radars at a 0.5km range or greater. That is a problem. GPS may be the worst victim of UWB interference: GPS operates at a very low margin above the thermal noise floor and is very susceptible to UWB impulses upsetting its moderate bandwidth raw data. That is a very serious problem. The proliferation of UWB systems will ensure the widespread, *total* failure of the Global Positioning System.

- **GPS Interference Test.** A UWB impulse radar motion sensor was placed near a GPS receiver. GPS satellite acquisition was *totally* blocked whenever the UWB unit was placed within 10-meters of the GPS receiver (UWB level > 200µV/m).

  Test parameters: UWB PRF = dithered 2MHz, UWB emissions = 660µV/m at 3m, spectrum = ~ flat across 1-2GHz, GPS receiver = Magellan Trailblazer XL.

- **FAA L-band Radar (ARSR-3).** Calculations show a UWB emitter will exceed the noise floor at a range of <u>411-meters</u>. That does not include any aggregate effect.

  Assumed ARSR-3 parameters: antenna gain = 34dB, noise figure = 4dB, frequency = 1300MHz, pulse width = 2µs, bandwidth = 0.5MHz (est.), UWB pulse desensitization = 3/.05 = 6x, antenna K = .62, equivalent desensitized noise floor at receiver antenna = 3.7µV/m. UWB parameters: 500µV/m in 3MHz bandwidth at 3m.

- **FAA S-band Radar (ASR-8).** Calculations show a UWB emitter will exceed the noise floor at a range of <u>534-meters</u>. That does not include any aggregate effect.

  Assumed ASR-8 parameters: antenna gain = 33dB, noise figure = 4dB, frequency = 2800MHz, pulse width = 0.6µs, bandwidth = 1.7MHz (est.), UWB pulse desensitization = 3/1.7 = 1.7x, antenna K = 1.5, equivalent desensitized noise floor at receiver antenna = 2.8µV/m. UWB parameters: 500µV/m in 3MHz bandwidth at 3m.

Similar calculations can be made for NEXRAD and TDWR. An RBW of 3MHz was used for bandwidth correction. At 1MHz RBW, the picture is even worse.

11B. Are there certain restricted bands where operation could be permitted, but not others? If so which bands and what is the justification?

Low spectral density operation should be permitted in restricted bands occupied by narrowband users or fixed satellite users where inherent receiver desensitization or antenna sidelobe rejection is a significant factor.

11C. If certain restricted bands were retained, what impact would this have on the viability of UWB technology?

Case 1. Retain a narrow restricted band such as 3.260 – 3.267GHz or 608-614MHz (radio astronomy).

UWB impact: Minimal. The UWB system could operate at > 7MHz PRF with its PRF harmonics set to straddle the restricted band. Alternatively, a single lowpass or a narrow bandreject filter would not introduce excessive ringing.

WB impact: None

Case 2. Retain a wide restricted band such as the 1.435-1.6265GHz.

UWB impact: Major. PRF techniques will not work and a wide bandreject filter would ring excessively and in a complex pattern (see Case 3).

WB impact: None

Case 3. Retain all restricted bands as is.

UWB impact: Major. PRF control will not work and a bandreject filter bank, as seen in Figure 6, would ring excessively and in a complex pattern, as seen in Figure 7.

WB impact: None, except as described in *Option* 2 on page 1, regarding operation in the restricted bands adjacent to the ISM bands.

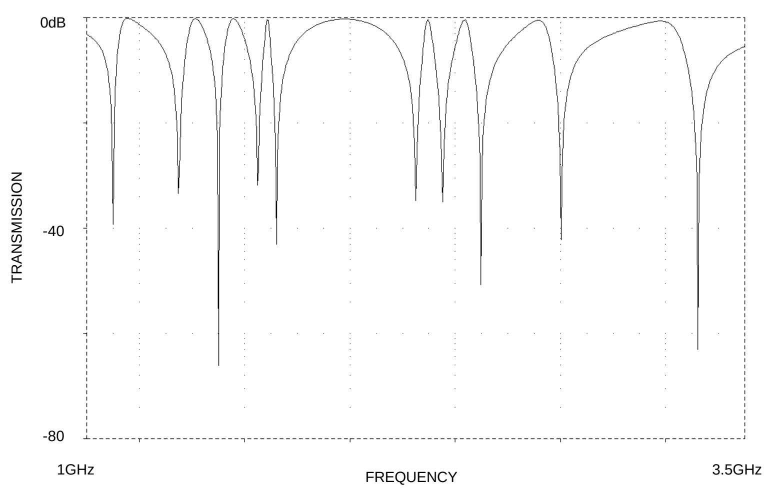

Figure 6. The frequency response of a 10-resonator notch filter covering the restricted bands from 1 to 3.6GHz. In practice, a much higher order filter would be needed to provide adequate rejection in the restricted bands. Such a filter would be expensive and would introduce even more ringing.

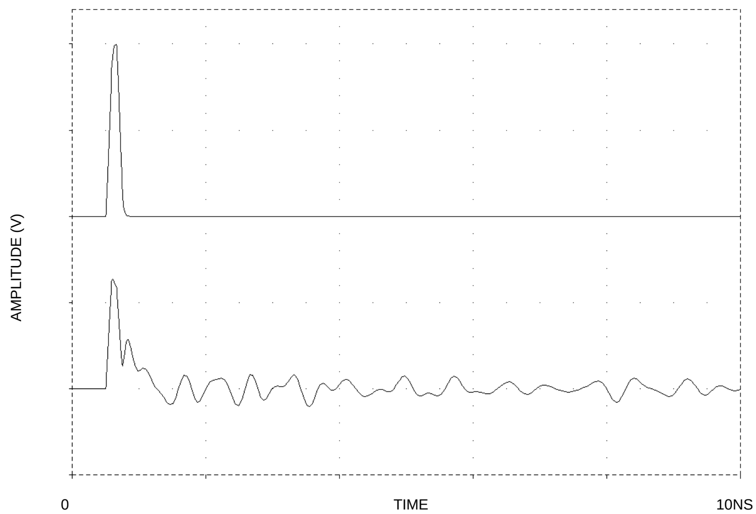

Figure 7. An impulse stimulus (upper trace) and a 10-resonator notch filter response (lower trace). Filter ringing is extended and complex.

The effect of notch filtering is to convert a UWB signal into an aggregate of narrowband signals. Filtering (1) smears UWB imaging, (2) stretches main bang ringing so weak returns are blinded by high levels of TX-RX coupling, and (3) eliminates the possibility for time-coded channelization. Depending on the filter Q and the PRF, filter ringing will extend from one impulse to the next and will build in amplitude to a greater extent than shown in Figure 7.

12A. Are the existing general emission limits sufficient to protect other users of the spectrum, especially radio operations in the restricted bands, from harmful interference?

The limits appear to be sufficient everywhere except in certain restricted bands such as the GPS, FAA, NEXRAD, and TDWR bands.

12B. Should different limits be applied to UWB systems?

The existing 500µV/m limit at 3-meters, with a 20dB duty-cycle credit for <10% duty-cycle is adequate (outside certain restricted bands), *provided pulse desensitization is not invoked.*

12C. Should we specify a different standard for UWB devices based on spectral power density? Should these standards be designed to ensure that the emissions appear to be broadband noise?

As in **12B**, the existing standards are adequate. The spectral power density measured by a 3MHz RBW spectrum analyzer accurately reflects the impact WB and UWB systems will have on other spectrum users.

A Rule to make emissions appear noise-like is spurious; it forces a format on low spectral density emissions that are already field-strength compliant. However, it would be in the UWB manufacturer's interest to noise-dither to lower spectral density and to have a wider compliance margin or to increase pulse amplitude. Advanced dithering techniques developed at TEM Innovations provide extremely smooth spectral characteristics at a very low cost.

12D. What is the potential for harmful interference due to the cumulative impact of emissions if there is a large proliferation of UWB devices? Could the cumulative impact result in an unacceptably high increase in the background noise level? Should the Commission limit the proliferation by restricting the types of products or should the rules permit manufacturers to design products for any application as long as the equipment meets the standards?

A large proliferation of UWB devices below 5.6GHz should ***not*** be permitted due to GPS and FAA radar vulnerability to interference. Above 5.6GHz environmental absorption will dominate, and wideband users will most likely have upward pointing antennas with good terrestrial sidelobe rejection.

12E. Should a limit on the total peak level apply to UWB devices?

Emission levels should be limited solely on the basis of impact to other users, as judged by a spectrum analyzer. A limit on pulse peak level is irrelevant. It would penalize systems using extremely short pulses, such as 10-picosecond wide pulses. Very short pulse systems need to operate at high peak levels to overcome the inherently high noise in their receivers, which may have instantaneous bandwidths of >30GHz. Yet, the pulse desensitization factor for conventional victims would be enormous, ~100dB. Picosecond-width systems may proliferate in the future as ASIC radars or chip-to-chip communicators as anticipated by research at Stanford.

12F. Can emissions below or above a certain frequency range be further filtered to reduce the potential for interference to other users of the radio spectrum without affecting the performance of the UWB systems?

Yes. In fact UWB antennas act as natural filters, so the addition of more filtration may have little effect on performance. For example, the classic W-shaped pulse commonly seen in impulse systems can be simulated by representing the UWB antenna as a second order highpass filter cascaded with a second-order lowpass filter, generally with 1GHz and 5Ghz corner frequencies respectively for a typical system. Adding a 2GHz highpass filter will tend to shorten the pulse and add some ringing. In some cases, such as for UWB tank level rangefinders, a combination of highpass and lowpass filtering would have little impact. For example, filter corners at 1.72 and 3.2GHz would allow over 1GHz bandwidth and thus sub-1ns pulse widths. Such a radar would emit 2-3 cycles of RF and would be quite suitable for precision ranging or general object detection. Employing a fast-start RF oscillator centered at 2.4GHz would practically eliminate the need for filtering and would not introduce any additional cost. This technology is already publicly available from Lawrence Livermore National Laboratory.

Filtering will have a pronounced negative impact on UWB radar *imaging* systems or any system where two-object spatial resolution is paramount.

12G. Are the existing limits on the amount of energy permitted to be conducted back onto the AC power lines appropriate for UWB devices?

On an energy basis, yes.

12H. What operational restrictions, if any, should be required to protect existing users?

For systems directed into the ground or concrete walls, a safety interlock could be employed to prevent accidental free-space radiation. Perhaps the Commission has yet to see a convincing interlock, but that may be a matter of redoubling the engineering effort in industry.

12I. Is the use of UWB modulation techniques necessary for certain types of communication systems; if so, for what purposes?

Yes, modulation is needed for a number of reasons:

- transmitting intelligence
- transmitting station identifiers
- transmitting an intermediate frequency that allows the UWB receiver to operate at an intermediate frequency (a sub-multiple of the PRF)
- dithering for interference reduction.

Modulation can take traditional formats: AM or OOK, PRF FM, or PRF PPM. Notably, the modulation bandwidth cannot exceed the PRF, which is far less than the RF bandwidth. Thus, modulation can only affect the distribution of energy within a broad spectral region, but not the width of that region.

13A. Is a pulse desensitization correction factor appropriate for measuring emissions from a UWB device? Should any modifications be made to this measurement procedure for UWB devices?

The FCC's tentative use of pulse desensitization (PD) correction is not appropriate; PD correction emulates a receiver with ***infinite*** bandwidth.

The Commission should specify compliance testing at 3MHz RBW, ***without PD correction*** because:

- Users with less than 3MHz bandwidth will have a lesser response.

- Users with 3 to 10MHz bandwidths will have a slightly greater response, but will also have a higher noise floor. *Effective* PD correction is minor—no more than 5dB.

- Users with greater than 10MHz bandwidth are most likely (1) channelized at <10MHz bandwidth, such as analog and digital TV, (2) spread-spectrum at <10MHz despread bandwidth, (3) directional with high side-lobe rejection, such as fixed satellite services, or 4) prophesies. In all cases, PD correction is inappropriate.

Should the Commission move forward with PD correction, many existing narrowband emitters will no longer meet spurious emissions tests since PD correction essentially piles a wide low-amplitude spurious spectrum into a tall imaginary spike. For many existing users, this imaginary spike would exceed 500μV/m and would force them off the air. PD correction is both inappropriate and unworkable.

The Commission's considerations on PD should apply equally to WB and UWB emissions, i.e., impulse and sinusoidal packets. There is no theoretical reason to assume that PD breaks down below some magic number of cycles. Tests at TEM Innovations on an HP8565 show that PD is accurate to within a few dB from 1-cycle to a large number of RF cycles. Tests were conducted using a TEM patent-pending fast-start PHEMT 5.8GHz oscillator and a sampling oscilloscope. It is reasonable to assume, however, that the transient response of the log amp in any particular spectrum analyzer may be suspect and should be checked for calibration over a broad range of pulse widths (a nearly impossible task, especially at the test labs).

13B. Would another measurement procedure that does not apply a pulse desensitization correction factor be more appropriate for determining the interference potential of an UWB device?

No. Spectrum analyzer measurements at 3MHz RBW most accurately reflect interference potential.

13C. The frequency range over which measurements are required to be made depends on the frequency of the fundamental emission. Is the frequency of the fundamental emission readily discernible for UWB devices? Are the current frequency measurement ranges specified in the rules appropriate for UWB devices or should these ranges be modified?

The fundamental emissions of all known UWB impulse devices are readily detectable with a spectrum analyzer. Existing measurement ranges are appropriate.

13D. Are the measurement detector functions and bandwidths appropriate for UWB devices? Should these standards be modified and, if so, how?

As in **13B**, spectrum analyzer measurements at 3MHz RBW most accurately reflect WB and UWB interference potential.

13E. Are there any other changes to the measurement procedures that should be applied to UWB devices?

No.

14A. Should the prohibition against Class B, damped wave emissions apply to UWB systems or is the prohibition irrelevant, especially in light of the relatively low power levels employed by UWB devices?

The prohibition is irrelevant to low spectral density devices.

14B. Comments are invited on any other matters or issues that may be pertinent to the operation of UWB systems.

None

CONCLUSION

The Commission is urged to consider the following *Options*:

1. Do not apply pulse desensitization correction (PD) to wideband emitters in the 15.209 bands. ***This Option will enable 90% of all low power WB and UWB sensor applications.*** *Operation in the restricted bands is* ***not*** *required.*

2. Combine Option 1 with the removal of the distinction between intentional and unintentional radiation, *only* for operation in the restricted bands adjacent to the ISM bands at 2.4, 5.8, 10.5 and 24GHz. ***This Option will enable nearly 100% of all WB and UWB sensor applications, including moderate power emitters.***

3. Combine Options 1 and 2 with licensed operation of intentional radiators in all the restricted bands. ***This Option will enable nearly 100% of all WB and UWB sensor applications and subsurface imaging.***

The Commission should continue its traditional role in fostering the development and deployment of new technologies by allowing one or more *Options*, each providing a greater amount of opportunity for commercial development. *Option* 1 is a solution for the commercialization of a vital new wideband technology while protecting the restricted bands. All that is required is a Memorandum to the test labs to not apply an inappropriate measurement "correction." Acceptance of wideband technology would then provide a like opportunity for UWB technology covered under *Options* 2 and 3.

The Commission should not warehouse valuable spectrum for unknown or prophesied users. Rather, it should be flexible in its spectrum management and take prompt action on these *Options*. Failure to do so will only encourage these technologies to flourish outside the United States at the expense of US competitiveness.

Sincerely,

Thomas E. McEwan